Research Note 84-100

Reverse Engineering of the BLACK HAWK (UH-60A) Helicopter:

Human Factors, Manpower, Personnel, and Training in the Weapons System Acquisition Process

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In a briefing format, this report on the BLACK HAWK (UH-60A) Helicopter summarizes an examination of human factors, manpower, personnel and training (HMPT) issues during the systems acquisition process. The report is one of four reverse engineering studies prepared at the request of GEN M. R. Thurman, Army Vice Chief of Staff. The four systems were studied as a representative sample of Army weapons systems. They serve as the basis for drawing conclusions about aspects of the weapons system acquisition process which most affect HMPT considerations. A synthesis of the four system studies appears in the final report of the Reverse Engineering Task Force, U. S. Army Research Institute.

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The Army is introducing new weapons systems to modernize its materiel resources at the greatest rate since World War II. At the same time, the Army is redesigning its force structure (Division 86) in light of the all-volunteer force. To insure that there will be enough soldiers with enough training to man the new complicated weaponry, the Army has designed a complex materiel acquisition process. This process is supposed to introduce human factors, manpower, personnel and training (HMPT) considerations into weapons system design early enough to prevent mistakes that will affect the system's operational utility and that will also add unanticipated expense to the weapon's life cycle costs.

Despite a number of regulations and instructions to include HMPT considerations in materiel acquisitions, the Weapons System Acquisition Process (WSAP) has not always been successful in producing weapons that are readily manned and operationally useful. This is true for several reasons. Techniques for predicting manpower requirements are not adequate. The documentation of HMPT requirements is slow and complicated, and it occurs too late in the WSAP to be effective. Finally, materiel developers often fail to understand the impact of HMPT requirements on the ultimate cost and operational utility of a new piece of hardware once it is fielded. Consequently, insufficient funds and effort are devoted to HMPT analysis and human factors engineering during early stages of system development. Such analyses have

often been scrapped when hardware budgets were exceeded and production schedules were slipping. Clearly, the WSAP needed more careful examination with respect to HMPT needs.

The Reverse Engineering Project was initiated at the request of GEN Maxwell R. Thurman while he was Deputy Chief of Staff for Personnel. It was his position that careful examination of the development process of several Army weapons systems that had already been fielded would identify critical events in the WSAP.

If proper consideration were given to HMPT issues at these critical WSAP events, the Army might be more likely to field more operationally useful systems. GEN Thurman began a series of projects to examine the WSAP. The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) was already intensively involved in systems-manning technology research. ARI was assigned to do "reverse engineering" on four weapons systems: STINGER, Multiple Launch Rocket System (MLRS), BLACK HAWK (UH-60A), and the Fault Detection and Isolation Subsystem (FDIS) of the M1 tank. Reverse engineering is the process of examining a product of the WSAP and, by using documentation and data on the weapons system, to determine what was done with respect to HMPT issues and what else could or should have been done to improve the result.

This report is on the UH-60A (BLACK HAWK), an Army utility helicopter. The report is self-contained, as are the reports on the three other weapons systems examined by the Reverse Engineering Task Force. There is also a report synthesizing the findings across the four weapons systems and their implications for the WSAP.

It is not the intent of this report to criticize the BLACK HAWK or any of the agencies responsible for its development. It is intended, rather, that this effort focus the Army's attention on improvements that can be made in the weapons system acquisition process, by using the BLACK HAWK acquisition as an example.

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BACKGROUND

The Army is introducing new weapons systems to modernize its materiel resources at the greatest rate since World War II. At the same time, the Army is redesigning its force structure (Division 86) in light of the all-volunteer force. To insure that there will be enough soldiers with enough training to man the new complicated weaponry, the Army has designed a complex materiel acquisition process. This process is designed to introduce human factors, manpower, personnel, and training (HMPT) considerations into weapons system design in a comprehensive fashion early enough to prevent manpower mistakes that will affect the system's operational utility or add unanticipated expense to the weapon's life cycle costs.

The Reverse Engineering Project was initiated at the request of GEN Maxwell R. Thurman while he was Deputy Chief of Staff for Personnel. It was his position that careful examination of the development process of several Army weapons systems that had already been fielded would identify critical events in the Weapons System Acquisition Process (WSAP). If proper consideration were given to human factors, manpower, personnel, and training issues at these critical WSAP events, the Army might be more likely to field more operationally useful systems. GEN Thurman began a series of projects to examine the WSAP. The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) was already intensively involved in systems-manning technology research. ARI was assigned to undertake a study based on the

"Reverse Engineering" of four weapons systems: STINGER, Multiple Launch Rocket System (MLRS), BLACK HAWK (UH-60A), and the M1 Fault Detection and Isolation Subsystem (FDIS). Reverse engineering is the process of examining a product of the WSAP and, by using documentation and data on the weapons system, to determine what was done with respect to HMPT issues and what else could or should have been done to improve the result.

APPROACH

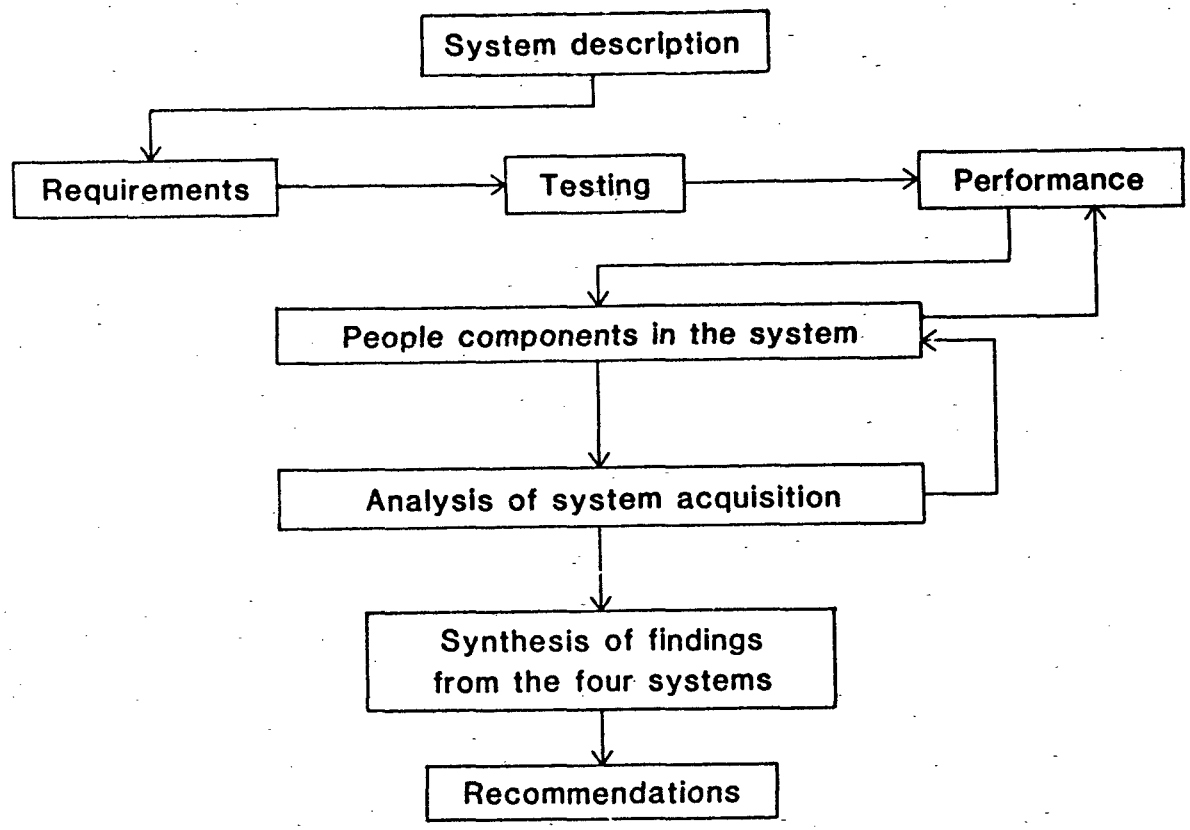
This report summarizes the study of the BLACK HAWK helicopter. Similar reports address the other three weapons systems encompassed by the Reverse Engineering Project. All four studies followed the same general approach illustrated in the figure below:

- The system was defined and described.
- Requirements documents were reviewed to determine how system performance was specified.
- Test and evaluation data were analyzed and compared to performance criteria.
- Problem areas in system performance were identified.
- HMPT factors were examined for their impact on the problematic aspects of system performance.
- The WSAP was reviewed to identify those facets that contributed to HMPT issues.

Findings from the four system studies were synthesized to arrive at conclusions regarding generic problems in the WSAP related to HMPT. Recommendations were developed for methods to improve the process

GENERAL APPROACH--REVERSE ENGINEERING

- STINGER
- Multiple Launch Rocket System
- BLACK HAWK
- M1 Fault Detection and Isolation Subsystem

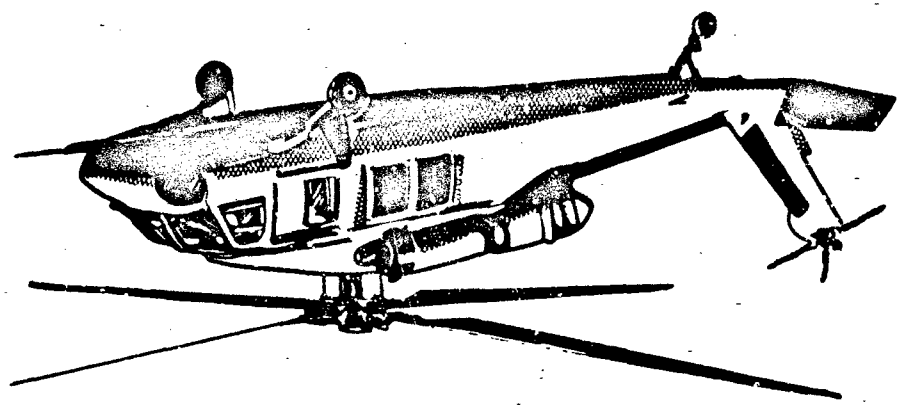


from an HMPT perspective. This information is summarized in the final report of the Reverse Engineering Task Force.

It is not the intent of the study or this report to criticize the BLACK HAWK or any of the agencies responsible for its development. Instead, it is hoped that this effort will help focus the Army's attention on improvements that can be made in the weapons system acquisition process.

MAJOR FINDINGS

1. If human-caused failures were omitted from the evaluation, the BLACK HAWK met its hardware performance specifications in the areas of human factors/safety and reliability, availability, and maintainability.
2. Failure to define mission performance requirements fully makes it impossible to evaluate system (man/machine) performance.
3. Delays in the acquisition of mission flexibility kits, peculiar ground support equipment, test measurement and diagnostic equipment, and flight and maintenance simulators has cost time, money and a lot of human ingenuity in compensating for the delays.
4. These findings all illustrate a concentration on hardware acquisition that makes it difficult to evaluate the performance of the man/machine system that is BLACK HAWK.



This report on the BLACK HAWK helicopter summarizes, in a briefing format, an examination of human factors, manpower, personnel, and training (HMPT) issues during the systems acquisition process. The report is one of four reverse engineering studies prepared at the request of GEN M. R. Thurman, Army Vice Chief of Staff. The four systems were studied as a representative sample of Army weapons systems. They serve as the basis for drawing conclusions about aspects of the weapons system acquisition process (WSAP) that most affect HMPT considerations. A synthesis of the four system studies appears in the final report of the Reverse Engineering Task Force, U.S. Army Research Institute.

The presentation begins with a description of BLACK HAWK, focusing on those aspects of the system especially pertinent to soldier concerns. A brief description of the acquisition process is provided. Then an analysis is shown of the relationship between system performance requirements and the outcome of BLACK HAWK test and evaluation. The impact of HMPT on continuing system performance problems is discussed. Inferences are drawn regarding those features of the acquisition process contributing to HMPT issues. Major findings are presented.

OUTLINE

The System: Its Mission and Acquisition

The System: Requirements and Testing

The Human: The Issues from Testing

- RAM
- Safety
- Mission Planning

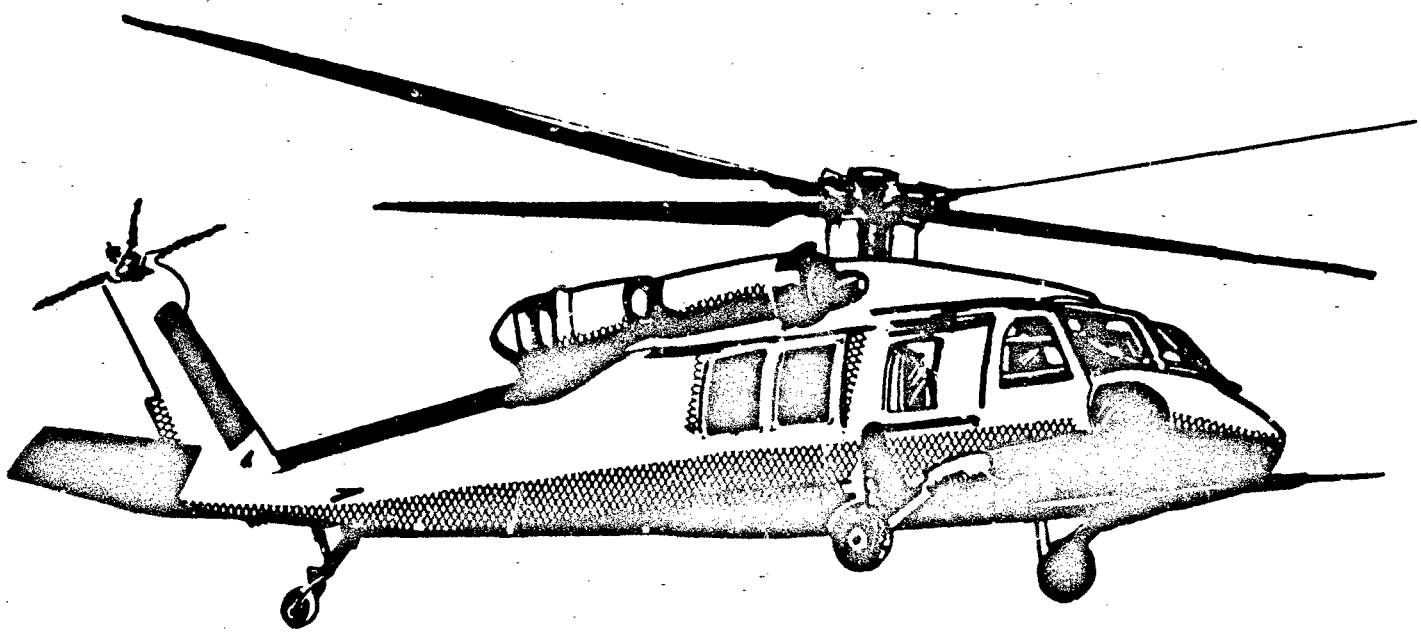
The New System: Implications for the Human

Conclusions

SYSTEM DESCRIPTION

The BLACK HAWK (UH-60A) is a twin-engine, single-rotor utility helicopter. It was known early in its acquisition as UTTAS (Utility Tactical Transport Aircraft System) and will be referred to here as BLACK HAWK. It is designed to be the Army's first true squad-carrying helicopter, capable of transporting up to 14 combat-equipped troops and a crew of 3 or an internal load of 2640 lb at 4000 ft pressure altitude and 95°F ambient temperature. Externally, it is intended to carry up to 8000 lb, which means, for example, that it can carry a 105mm howitzer and its crew.

The BLACK HAWK was designed to be faster than the Huey it replaces. It was intended to carry a larger payload and to be more crashworthy and survivable than the Huey.



BLACK HAWK
(UH-60A)

MISSION

The BLACK HAWK supports the Army's airmobility doctrine for employment of land forces in the 1980s. Its mission is to transport air assault troops, to provide short range combat support, to provide combat service support (equipment and troop movement), to carry the air cavalry, and to provide aeromedical evacuation.

BLACK HAWK MISSIONS

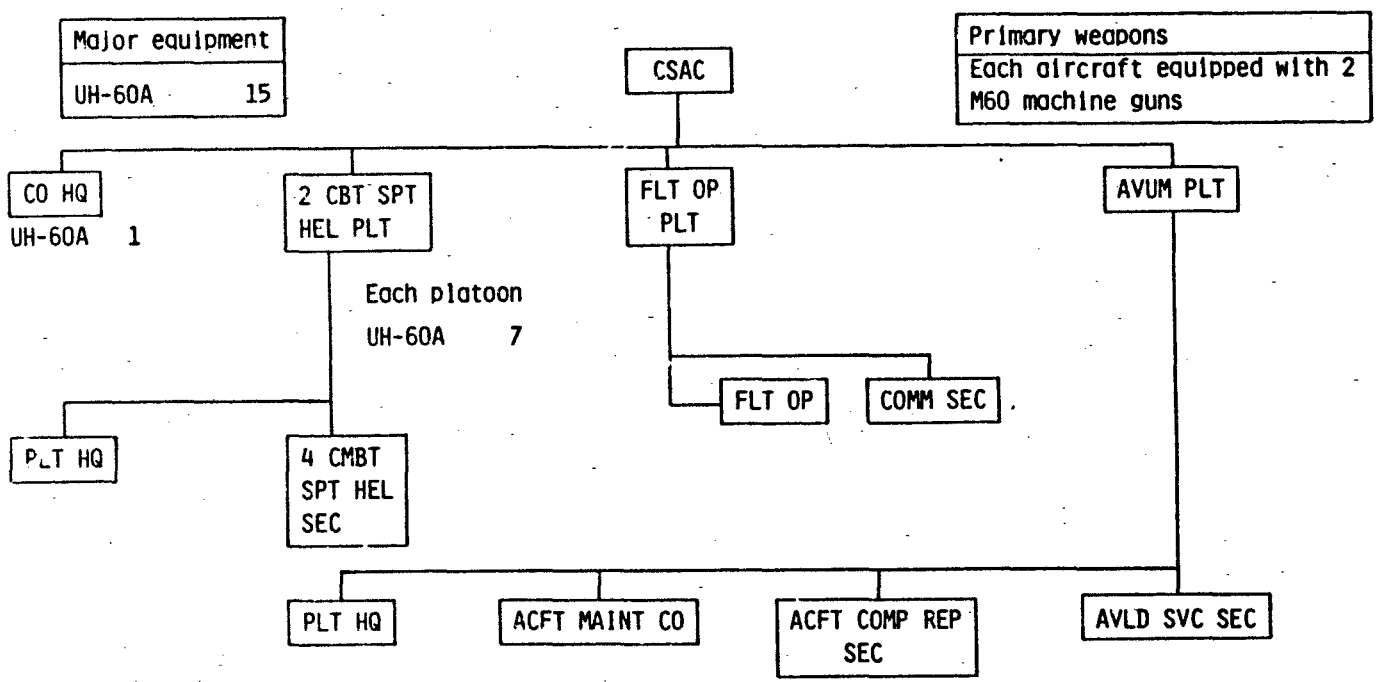
- Air assault
  - Troop movement
- Air cavalry
  - Troop movement
  - Cavalry reconnaissance
- Combat support
  - Resupply and forward area rearming and refueling point (FARRP) operations
- Combat service support
  - Maintenance equipment movement
- Aeromedical evacuation

ORGANIZATION

The BLACK HAWK can be assigned to a Combat Support Aviation Company (CSAC) in a Combat Support Aviation Battalion (Air Assault Division), to a Combat Aviation Battalion (Armored, Infantry, Mechanized, or Airborne Divisions), to Corps, to the Air Cavalry, or to an Air Ambulance Company. The organization of a typical CSAC is shown below. Especially important is the large part of the CSAC devoted to maintenance.

COMBAT SUPPORT AVIATION COMPANY

Combat Support Aviation Battalion
Air Assault Division

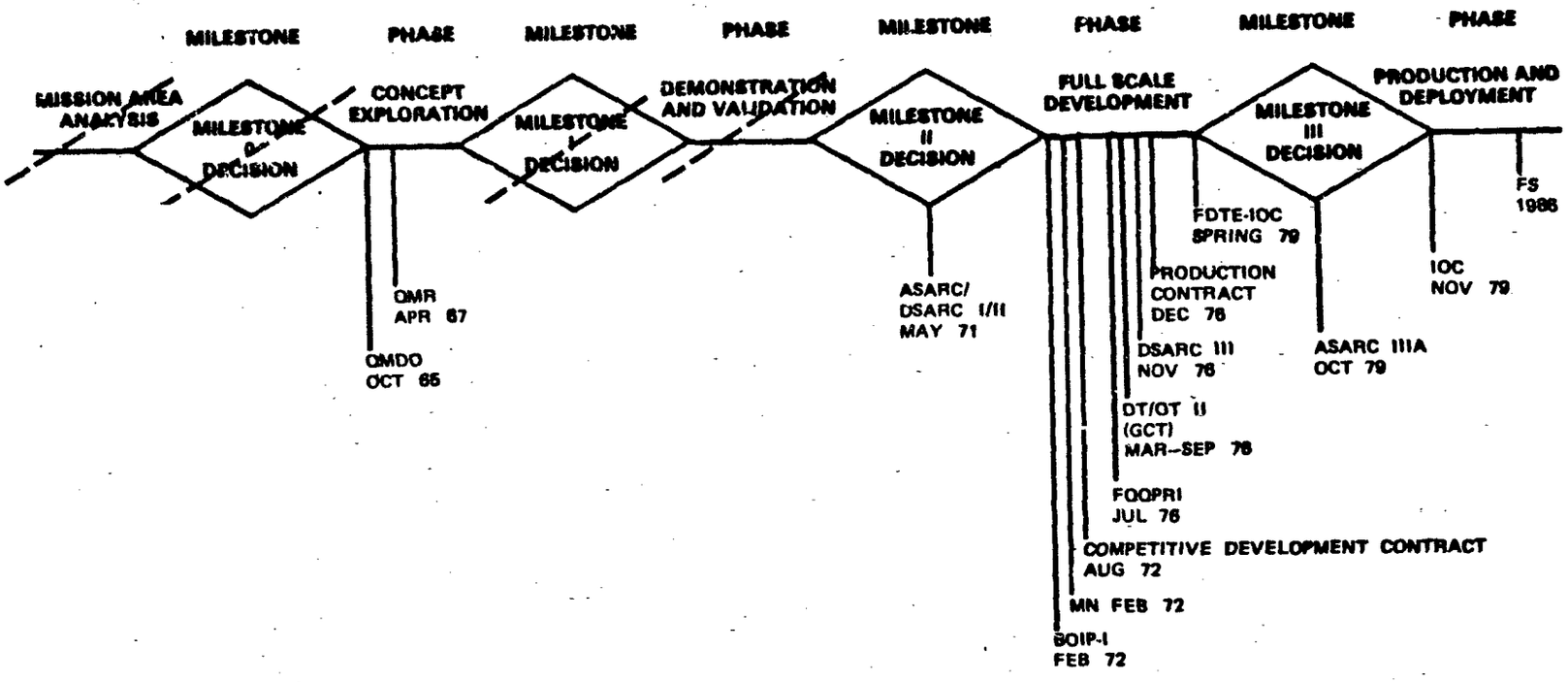


ACQUISITION HISTORY

BLACK HAWK was developed in response to needs that became apparent during the Vietnam Conflict. At that time, the system acquisition model was different from the Life Cycle System Management Model (LCSMM) we know today, but the model would be equivalent to the concept development phase ran from 1965 to 1971. The first requirements document, the Draft Proposed Qualitative Materiel Requirements (DPQMR), was published during this time, along with the first Cost and Operational Effectiveness Analysis (COEA). The events of what we now call the demonstration/validation phase were combined with the engineering development phase. This full-scale engineering development (FSED) was authorized in May 1971 by the favorable decision of the Defense Systems Acquisition Review Council (DSARC) I/II.

On the basis of that decision, in March 1972 the General Electric Company was awarded a contract for development of the engine. Competitive contracts for development of the airframe were awarded to the Boeing-Vertol and Sikorsky Companies in August 1972. Development and operational testing (DT/OT) was carried out in 1976 and included Government Competitive Tests (GCT). In November 1976, some 51 months after the airframe contract was awarded, a DSARC III decision authorized the Army to proceed with initial production.

BLACKHAWK
MAJOR ACQUISITION PHASES AND MILESTONES



The Army type classified the airframe as standard and awarded a maturation and initial production contract to the Sikorsky Company in December 1976. There was no DT III/OT III but a Force Development Test and Experimentation (FDTE) was carried out in mid-1979 to resolve the issues raised in OT II. By October 1979, 19 aircraft had been delivered to the Army, and an Army System Acquisition Review Council (ASARC IIIA) decision approved continued production. Initial operational capability (IOC) was achieved by the 101st Airborne Division (Air Assault) at Fort Campbell, Kentucky, in November 1979.

There are three points in particular to be noted:

1. The acquisition took 14 years from the Qualitative Materiel Development Objective (QMDO) until IOC.
2. The engineering development was competitive between Boeing and Sikorsky.
3. There was only one DT/OT, called DT/OT II, in 1976.

EQUIPMENT

The items listed below were specifically included in the BLACK HAWK acquisition program. They form the machine part of the BLACK HAWK weapon system.

BLACK HAWK EQUIPMENT

- 1107 BLACK HAWK helicopters
- Mission flexibility kits
- Peculiar ground support equipment
- Test, measurement, and diagnostic equipment
- 15 BLACK HAWK flight simulators
- 13 types of maintenance training simulators

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This section discusses the performance requirements for BLACK HAWK and the results of testing and evaluation (T&E) during the acquisition process.

The performance requirements listed here are from the BLACK HAWK Request for Proposal (RFP), December 1971. These requirements are crucial to BLACK HAWK's mission performance. The capacity of the aircraft and its power-to-weight based performance make certain types of missions possible. Good reliability, availability, and maintainability (RAM) characteristics are essential for readiness. A machine cannot be reliable or maintainable, and therefore available, unless good human factors engineering (HFE) is applied in the design stages. Therefore, RAM characteristics have profound HMPT implications. The criteria listed here are those against which BLACK HAWK was judged during DT/OT. Performance measures during DT/OT do not traditionally include the incidents caused by human error.

SELECTED PERFORMANCE REQUIREMENTS

Mission Capacity	
Number of troop seats	11/14
Number of litters	6
External load	8000
Internal load	2640
Power-to-Weight Performance	
Rate of climb (ft/min)	450-550
Cruise speed (kn)	145-175
Endurance (hrs)	2.3
Availability	
Inherent	.97
Achieved	.92
Reliability	
Mission (probability 1 hr mission)	.999+
Safety (probability 1 hr mission)	.997+
Mean time between failures (flt hr)	4
Mean time between removals (flt hr)	1500
Maintainability	
Mean time between maintenance (flt hr)	1.7
Unscheduled (corrective) maintenance (mmh/fh)	2.8
Scheduled (preventive) maintenance (mmh/fh)	1.0

Source: *Request for Proposal*, December 1971.

The mission capacity requirements were demonstrated in DT/OT II. The BLACK HAWK's power-to-weight performance did not meet its criteria in DT/OT II. Subsequently, excess weight was removed and the power-to-weight criteria were met by FDTE. However, since only fragmentary operational criteria were established for measuring the system's capacity for nap-of-the-earth (NOE) flight, for providing a gunnery platform, or for performing complete cargo/personnel-carrying missions, the BLACK HAWK's adequacy for these tasks could not be assessed.

TEST AND EVALUATION RESULTS

Demonstrated in DT/OT II and FDTE

- Mission capacity
- Power-to-weight performance

Not demonstrated because they were not fully tested and evaluated

- BLACK HAWK's adequacy for performing complete missions requiring nap-of-the-earth flying
- BLACK HAWK's adequacy as a gunnery platform
- BLACK HAWK's adequacy for performing complete cargo/personnel carrying missions

BLACK HAWK NAP-OF-THE-EARTH AND NIGHT REQUIREMENTS

The BLACK HAWK Materiel Need (Engineering Development) (MN(ED)) stated clearly the requirement that the aircraft should be designed "to permit safe nap-of-the-earth operation" and be capable "of conducting day and night missions." This requirement obviously has hardware implications (e.g., high power-to-weight ratio for better maneuverability). It also has important HMPT implications: the machine must be designed to aid the individual to do something that cannot be done well unaided (i.e., to see well enough to fly at night).

BLACK HAWK NAP-OF-THE-EARTH AND NIGHT REQUIREMENTS

"It will be highly maneuverable to permit safe nap-of-the-earth operation (less than 300 feet above the surface) including formation flight at maximum airspeed under daylight visual flight conditions and be capable, at appropriate higher altitudes, of conducting day and night missions under visual and instrument conditions."

Source: *UTTAS Materiel Need (ED)*, February 1972, p. 2, para. 1.2.1.

TESTING OF MISSION CAPACITY

Why didn't the testing and evaluation of BLACK HAWK provide information about the system's capacity to perform certain missions? In each case, some of the following points were true:

1. Accuracy and/or time criteria were not developed and linked together.
2. Aircraft were not instrumented for testing during OT II, so the only performance measure was speed. Handling, maneuvering, and navigation were not measured fully in all significant conditions.
3. Missions were measured in unrelated fragments, so interaction effects on ultimate mission outcome could not be evaluated.

Without adequate performance criteria, mission performance cannot be evaluated:

- Accuracy and time criteria were not developed and linked for mission performance.
- Handling and maneuvering were not measured fully in all significant conditions.
- Entire mission cycles were not measured.

The chart below shows that, by the usual hardware measures, BLACK HAWK met its RAM performance requirements by the FDTE.

BLACK HAWK HARDWARE PERFORMANCE

RAM Measures of Effectiveness	MN Crit[1]	TRADOC MAV[2]	DT II[3]	OT II[4]	FDTE[5]	FDTE (last 200 flt hrs)
System mean time between failures (hours)	4.00	2.70	2.32	2.54	3.32	4.12
System mean time between mission aborts (hours)	75.00	55.10	16.00	28.60	29.68	
Mean time between replacement of dynamic components[6]	1500.00	--				
Corrective maintenance manhours per flight hour	2.80	8.09	1.44	1.32	1.04	.37
Scheduled maintenance manhours per flight hour	1.00	2.17	1.27	.72	.47	.47
Operational availability	.82	.75	.85	.84	.76	
Achieved availability	.92	--	.95	.95		

[1] Materiel Needs criteria.

[2] TRADOC minimum acceptable value.

[3] *IER of DT II*, AMSAA, December 1976.

[4] *IER of OT II*, OTEA, December 1976.

[5] *IOC FDTE*, U.S. Army Aviation Board, January 1980.

[6] No BLACK HAWK was flight tested for 1500 hours in any of the three tests; therefore, no data are reported.

RAM AND HUMAN ERROR

This detail from the preceding chart shows that the values for some criteria can be calculated in different ways. For example, the 4.0 performance requirement for system mean time between failure was met only when it was measured during the last 200 flight hours of the FDTE. There may be valid reasons for excluding the earlier flight hours of the test; nevertheless, the criterion of the MN was met only during the last 200 flight hours. Furthermore, because of the scoring criteria permitted by usual procurement practices, all soldier-produced failures were excluded from the calculation of system mean time between failures and system mean time between mission aborts. When soldier-produced failures are included, mean time between failures in hours falls 30%, and mean time between aborts decreases 40%. This occurs in the DT/OT test environment, which is probably not as stressful for the soldier or the equipment as the battlefield would be. Yet it is more realistic when human-produced failures are included than when they are excluded.

Furthermore, these reduced reliability factors seriously decrease the system's availability.

	MN Criteria (hours)	FDTE (hours)	FDTE (last 200 flt hrs)
System mean time between failures	4.00		
Human errors excluded		3.32	4.12
Human errors included		2.32	
System mean time between mission aborts	75.00		
Human errors excluded		29.68	
Human errors included		17.65	

REQUIREMENTS AND HUMAN ERROR

The MN criteria for these measures of effectiveness (MOE) were almost certainly intended to refer to hardware failures only, so the developers cannot be faulted for interpreting their test results in terms of hardware only. However, since human error decreases mean time between mission aborts by 40% and since such errors do occur, it seems reasonable that future requirements documents should specify minimum acceptable values for MOEs, both with and without human error.

Criteria development and testing procedures for BLACK HAWK did not permit a diagnosis of reasons for soldier-produced errors. In fact, the data for soldier-produced error were not even presented for DT/OT II, as for the FDTE. The data may exist somewhere, but they have not been presented in a useful form in the test reports.

Future Requirements Documents . . . need criteria for measures of effectiveness that include human-produced errors.

Future Test and Evaluation . . . needs to present and evaluate data, including human errors.

HUMAN PERFORMANCE: A PART OF SYSTEM PERFORMANCE

There are other crucial requirements for BLACK HAWK's mission performance, including the pilot's skill, navigational abilities, and mission-oriented training. Other requirements include adequate maintainer training and sufficient numbers of personnel in appropriate MOS. Such requirements are not traditionally cited in weapons system performance requirements, even though they are as crucial as the hardware requirements.

HUMAN PERFORMANCE: A PART OF SYSTEM PERFORMANCE

- Operators
  - Pilot skills
  - Navigational ability
  - Mission training
  - Sufficient numbers
- Maintainers
  - Maintainer skills
  - Sufficient numbers

TEST AND EVALUATION CONCLUSIONS

In areas in which BLACK HAWK did not meet, or just barely met, specific performance criteria, the data were not presented in such a way that specific sources of the inadequacies could be determined. That is, if the inadequacy were due to human error, the cause of the error could not be determined. Furthermore, the operationally oriented tests were designed and conducted in a manner that did not fully stress the system as would occur on the battlefield, nor did they determine the probability of the success of performing full missions. Finally, although indications are that BLACK HAWK was a potentially useful system, decisionmakers were not presented with information that was adequate to predict the probability of mission success on the battlefield.

CONCLUSIONS

- BLACK HAWK test and evaluation did not permit identification of soldier-produced errors that might have caused inadequate system performance.
- Operational testing did not fully stress the system.
- Decisionmakers could not know probability of mission success from BLACK HAWK test and evaluation.

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In examining the BLACK HAWK's performance as tested in DT/OT II, at least three major issues with profound HMPT implications came to light: RAM, safety, and mission planning. Each issue is discussed in this section.

Since the BLACK HAWK was developed to perform the same basic mission as the UH-1, the Army had a lot of information, gained through years of experience with the UH-1, for projecting the BLACK HAWK requirements. Nevertheless, manpower predictions varied widely for some MOS. For example, in deriving the number of MOS 67T (tactical aviation unit maintenance (AVUM) transport helicopter repairers) needed in a typical CSAC platoon, the U.S. Army Training and Doctrine Command (TRADOC) found it had its choice of numbers.

When the number of positions for MOS 67T is calculated using direct productive annual maintenance manhour (DPAMMH)/flight hour data, very different estimates result, depending on the source of the DPAMMH estimates. These estimates are shown below; all are substantially lower than the 24 positions listed in the current table of organization and equipment (TOE). The last estimate is only 79% of the number actually specified in the TOE.

MOS 67T POSITION ESTIMATES IN CSAC

Source	Number of Positions
QQPRI (from early LSAR) (November 1976)	4
PM estimate (January 1980)	13
TRADOC HQ estimate (January 1980)	6
LSAR (from later LSAR) (January 1982)	10
BLACK HAWK (MACRIT) (AR 570-2)	19
Current requirement (October 1983) (TOE 07269J000, CSAC AASLT DIV)	24

Early logistics support analysis record (LSAR) estimates tend to be low; they are based on data generated early in full-scale engineering development. The LSAR data are used to generate the BOIP and the Manpower Analysis Paper (MAP), and these are the numbers presented to the ASARC/DSARC and used for Program Objective Memorandum (POM) estimates. It is probably no accident that the smallest estimate is the one presented to the ASARC. The Manpower Authorization Criteria (MACRIT) estimate of 19 positions, which is the highest, is based on UH-1 usage. In developing the CSAC TOE, TRADOC used the early LSAR estimate of 4 MOS 67T positions to each AVUM platoon. The BLACK HAWK Post-Fielding Review (April 1982) discovered that this number is "inadequate to meet the maintenance demands.... It has been recommended that FORSCOM advise DA DCSPER of requirements for additional 67T10 personnel and request adjustment of TOE for BLACK HAWK units."

MANPOWER ESTIMATES

- Estimates varied widely from different sources.
- Logistics support analysis record data collection was stopped in the middle of engineering development because of lack of funds.
- Authorization for MOS 67T was underestimated by 21% to 600% depending on the source of the estimate.
- Funds should have been provided to continue logistics support analysis record data collection.

Consequences . . .

- It has been necessary to undertake new recruitment initiatives.
- Enough people were not trained in time to test the system properly.

Early BLACK HAWK system documents, beginning with the MN, indicate that the Army took advantage of lessons learned from the UH-1. For the most part, the Army's experience with the UH-1 enabled manpower planners to predict accurately the necessary number of maintenance positions other than those for MOS 67T. However, personnel with the skills and training to fill those positions were not available by IOC. The BLACK HAWK Post-Fielding Review (1982) reports that there were shortages of critical avionics maintainers.

"All units were at or near their authorized overall personnel strengths. However, shortages in some MOS's existed (MOS's 35K and 68F at skill levels 1 and 2 (E-4 and E-5)). These shortages are critical to the units because the majority of the failures and related maintenance actions are directly related to the avionic/electrical systems. FY-83 accessions and training programs have been established which will correct these shortages."

Source: *Force Modernization Report*, June 1983.

The Army has several alternatives for trying to solve the problems caused by shortages of personnel with critical skills.

Solutions . . .

- Alter system design to use fewer such people;
- If this can't be done, use the early manpower estimates to recruit more people; or
- Aircraft production could be slowed to reduce the number of units requiring these skills; or
- If shortages Army-wide are sufficiently severe, production could be stopped altogether.

The BLACK HAWK acquisition was supposed to include training hardware (production aircraft parts), programable part-task trainers (hydraulics, electrical, and other systems), and a composite trainer (the complete aircraft without the outer skin). When the part-task trainers and the composite trainer arrived at the U.S. Army Transportation School (USATSCH), some were completely unusable; the rest were only 30-40% effective (subject matter expert estimate). The composite trainer met only 30% of the engineering specifications for current production aircraft.

Procurement of these devices had been assigned to Program Manager - Training Devices and Equipment (PM-TRADE), which was new then, but neither funds nor responsibility for forwarding engineering change proposals to the contractors had been designated. Furthermore, for competitive reasons, contractors had not initially been given sufficient design information to do a credible job.

The consequences for the maintenance training program at USARSCH were disastrous. The training devices were unusable, and much of the training burden had to be shifted to the units.

MAINTENANCE TRAINING DEVICES

Problem

- Maintenance training devices did not match the aircraft.

Reasons

- Procurement assigned to PM-TRADE (then new) but not funds or responsibility for upgrading as engineering change proposals were made.
- Contractors were not initially given sufficient aircraft design data.

Consequences

- Training devices were unusable at the U.S. Army Transportation School.
- Burden on unit training was increased.

A number of actions have been taken to remedy this situation. USATSCH fabricated a composite trainer and some other trainers from the airframes of two crash-damaged prototypes. PM-TRADE has changed its administrative procedures; it has also contracted with Sikorsky to evaluate the effort and cost to upgrade totally all maintenance training devices. This upgrade began during the first quarter of FY83 and will be finished by April 1984--4-1/2 years after the BLACK HAWK IOC.

MAINTENANCE TRAINING DEVICES

Actions taken:

- o U.S. Army Transportation School manufactured its own composite airframe and some smaller trainers.
- o PM-TRADE administrative procedures were changed.
- o PM-TRADE commenced contract to upgrade devices, starting 1st quarter, FY 83, and ending April 1985 (4-1/2 years after BLACK HAWK IOC).

While engineering for the BLACK HAWK helicopter itself was well done, the engineering development of several items associated with it was not addressed as thoroughly. These include peculiar ground support equipment (PGSE) and test measurement and diagnostic equipment (TMDE) that are peculiar to the BLACK HAWK. The development of these items was allowed to slip, and intensive engineering was not applied to their development. These items are necessary for operational use of the BLACK HAWK. Human engineering requirements for these items should have been handled at the same time as those of the item they support. In fact, some of these items are still in the design stages and "quick fixes" are being used to meet operational demands.

SUPPORT EQUIPMENT

- Human factors, manpower, personnel, and training requirements for peculiar ground support equipment and test measurement and diagnostic equipment not identified before initial operational capability.
- Production of these items was allowed to slip.
- No operational testing was done.
- Force development testing and experimentation was only partial.
- These items are necessary for maintenance and operational use of BLACK HAWK; their human factors, manpower, personnel, and training requirements should have been considered much earlier in the acquisition cycle.
- Requirements for some of these items are only now being identified.

The consequences of delay in identifying special tools and test equipment are more maintenance down time, which affects system availability, and the excessive use of spare parts, many of which are at a premium for BLACK HAWK.

These conclusions were cited in the BLACK HAWK Force Modernization Report (April 1983):

"1. Special tools required for a fielded system must be available concurrently with the end items.

2. Special test equipment must be provided to user installations if maintenance manuals specify peculiar tasks."

CONSEQUENCES OF DELAYING SUPPORT EQUIPMENT

- Increased maintenance down time
- Excessive use of spare parts
- Reduced availability

The MN specified that the degree of operator and maintainer skills required by UTTAS should not exceed that required by the then-current utility helicopter, the UH-1. However, at that time there was no way to operationalize that statement--no way to determine empirically the level of skill required by UH-1 maintainers and compare it to the level of skill thought to be required by the not-as-yet designed UTTAS. The Army Research Institute's HARDMAN and MIST projects, still under development, are steps in this direction.

PERSONNEL SKILLS AND ABILITIES

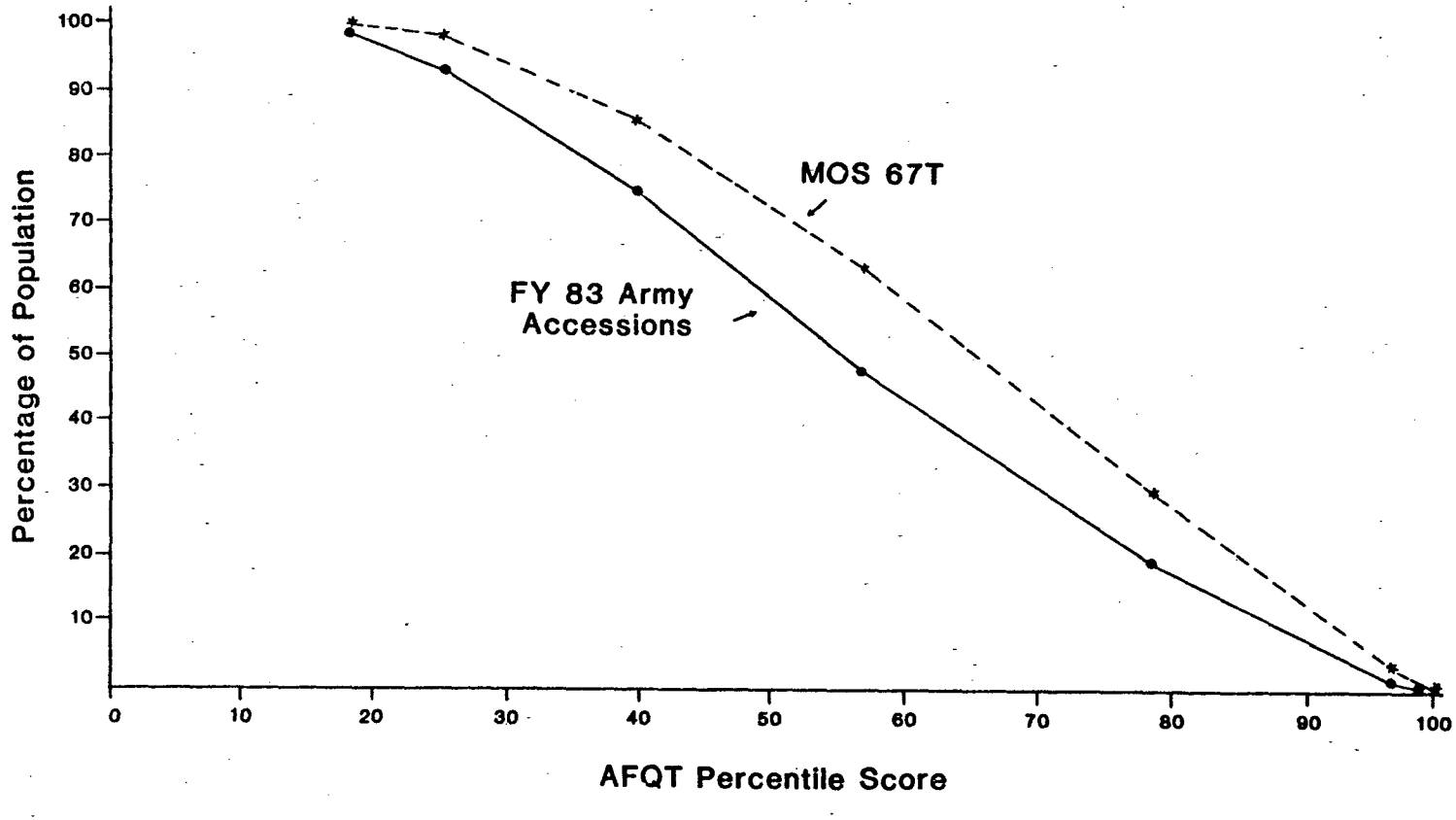
"7.1.2.1 Flight crew. The UTTAS will normally be operated by a minimum of three crewmembers possessing skills and knowledge similar to those operating present utility helicopters.

7.1.2.2 Maintenance personnel. The degree of skill required at each level of aircraft maintenance should not exceed that required for current utility helicopters except for the complication introduced by advanced avionics or weapons systems. The degree of complication should not present more than the normal requirement for transition associated with introduction of new equipment. Identity of personnel will be based upon the QQPRI data."

Source: *BLACK HAWK Materiel Need*, February 1972.

Army-wide accessions for FY 83 scored higher as a group on the Armed Forces Qualifications Test (AFQT) than did accessions in previous years. As a group, those accessions with MOS 67T as training MOS scored even higher than the rest of their cohort. We know that BLACK HAWK maintainers are currently maintaining the system. We do not know whether soldiers who score lower on the AFQT can do the job, because they have not been tested.

ARMED FORCES QUALIFICATION TEST DISTRIBUTION, FY 83



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OUTLINE

The System: Its Mission and Acquisition

The System: Requirements and Testing

The Human: The Issues from Testing

- RAM
- → Safety
- Mission Planning

The New System: Implications for the Human

Conclusions

BLACK HAWK's design requirements for safety included criteria for structural integrity, energy absorption, and postcrash environment safety. Furthermore, the helicopter was to be engineered to reduce "accidents resulting from errors in operation and maintenance."

BLACK HAWK DESIGN

- Structural integrity
- Energy absorption
- Safe postcrash environment
- Accident reduction

Army Materiel Systems Analysis Activity (AMSAA) concluded during OT II that the system had met the safety requirements of the MN and that it provided significant advantages over the UH-1.

BLACK HAWK SAFETY--TEST AND EVALUATION

"Human Factors Engineering (HFE)/Safety--Although some problems were surfaced during government development testing, the overall aspects of the man-machine interface and crash safety are evaluated as excellent for the UTTAS prototypes. The production UTTAS will provide significant advantages over the UH-1H in the HFE/Safety area."

Source: *AMSAA*, 1976.

The U.S. Army Safety Center (USASC) has analyzed the 16 BLACK HAWK accidents that occurred from October 1979 through October 1983. USASC has determined that the safety factors designed into the BLACK HAWK have saved lives; fatalities have occurred when impact conditions exceeded design requirements. Half of the 16 accidents were attributed to human error. Four more were attributed to combined materiel and human causes; three of those were attributable to improper maintenance. The largest single cause of accidents was crew error during night flight (6 out of 16). USASC concluded that "planning guidance and acceptable parameters for night tactical missions should be improved."

Good News:

- o BLACK HAWK safety features are effectively reducing losses.
- o Fatalities in accidents have been due to impact conditions exceeding design requirements.

Bad News:

- o Largest single cause of accidents was crew error during night flight (6 out of 16 accidents).
- o Risks have not been defined for:
  - -- night operations
  - -- formation flight
  - -- night vision goggles
- o Capability to perform under these conditions was required by BLACK HAWK Materiel Needs and is currently required by doctrine.

Since BLACK HAWK requirements documents and current Army doctrine require the BLACK HAWK to perform during night operations and formation flight, and since accidents are most frequent in these categories (12 out of 29), it is clear that even the best of designs is not enough. Adequate training and planning, as well as acceptable parameters for these missions, are also required.

SYSTEM SAFETY

Requires . . . Training
Planning
Mission parameters

Plus . . . Good hardware design

OUTLINE

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The problem of mission planning is not confined to safety issues. Mission planning was another issue raised in the testing of BLACK HAWK against its performance specifications. Mission planning includes the hardware necessary to modify the BLACK HAWK for the performance of different missions, being certain that pilots are trained to carry out different missions, and planning ahead for hardware design and human resources that will use the full capabilities of the helicopter.

PROBLEMS IN MISSION PLANNING

- Mission flexibility kits
- Pilot training
- Hardware and manpower for new missions

The current RFP for BLACK HAWK (1984) calls for six mission flexibility kits (MFK), only one of which was not in the original RFP. Some of the MFK were not available at IOC. These kits are currently in various stages of fielding. The full range of training requirements has not yet been assessed.

MISSION FLEXIBILITY KITS

	New?	Available at IOC?
Kit, air transportability (loading set)	No	Yes
Kit, winterization	No	Yes
Kit, rescue hoist adapter	No	No
Kit, medical evacuation	No	No
Kit, blackout	No	Yes
Kit, external stores support system removable provisions	Yes	No

The issue of training devices and their failure to be available at weapons system IOC is reported to be an Army-wide problem. The BLACK HAWK flight simulator is no exception.

Flight simulators are used for gunnery training, instrument flying proficiency, and training for emergency procedures. In 1976 a contract was awarded to Singer-Link Company to provide the BLACK HAWK flight simulator. As late as 1980, an Army Modernization Information Memorandum (AMIM) projected that the first of 6 flight simulators would be available in 1983, the rest by 1986. The current BOIP now projects that the first 2 flight simulators will not be available until 1986, with 13 more available by 1990. Of the 1,107 BLACK HAWK expected, 450 have already been produced--over one third; yet only 1 flight simulator is available now at Fort Rucker, Alabama.

FLIGHT SIMULATORS

1980 Army Modernization Information Memorandum		1983 Basis of Issue Plan
(FY 80	1 prototype)	
FY 81	0	(1 prototype at Fort Rucker)
FY 82	0	0
FY 83	1	0
FY 84	3	0
FY 85	1	0
FY 86	1	2
FY 87	-	4
FY 88	-	4
FY 89	-	4
FY 90	-	1
Total	6	15

How important is the delay in the delivery of the BLACK HAWK flight simulator? TRADOC Systems Analysis Agency (TRASANA) summarized the impact of the problem in a training development study (TDS-19-82, April 1982).

> "If a more cost and training effective method of training UH-60A aviators cannot be found and the cost of operating the aircraft continues to escalate, then it will be necessary to curtail a part of the flying-hour program. This flying-hour program consists of two parts: mission dollars and training dollars. Since the mission is the only reason for the units' existence, it becomes very apparent that the money for training will be reduced to a minimum in order to support the missions. This translates to less proficient pilots, since these same missions do not necessarily include all those tasks a pilot needs to practice in order to remain proficient in the aircraft" (pp. 1-2).

FLIGHT SIMULATOR

- BLACK HAWK operating costs are escalating.
- Flying-hour program in the units consists of mission dollars and training dollars.
- The units exist because of the mission.

Therefore, training, not mission, dollars will be cut and pilots will become less proficient.

Source: *TRASANA, TDS-19-82*, April 1982.

If pilots are going to receive less training, the decision should be made as a matter of policy not as an accidental fallout of a failure of the WSAP--the failure to have training devices available on time.

Is this how we want our training policy decided?

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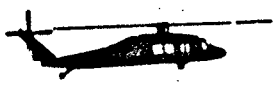

The New System: Implications for the Human

Conclusions

A Required Operational Capability (ROC) for the BLACK HAWK Improvement Program was submitted in May 1982. This ROC, which is currently being reviewed in TRADOC, calls for improvements to "correct current operational deficiencies and align the aircraft capability with the AirLand Battle 2000 concept." In its technical assessment section, the program is called "low risk." IOC for the improved BLACK HAWK is predicted for first quarter, FY 89.

There are four points to be made in the discussion of this new ROC:

1. The requirements of the new ROC may exacerbate minor problems on the old BLACK HAWK.
2. The ROC places new demands on the human and the hardware that designers of the old BLACK HAWK could not have anticipated.
3. The new ROC anticipates no changes in manpower/force structure requirements, even though tasks and skills for the operation, maintenance, and support of the system have yet to be assessed.
4. Training assessments have been made and specify that training devices will be modified to support training on the improved BLACK HAWK. Training devices have yet to arrive for the "old" system.

This does not mean that the BLACK HAWK should not be improved. If these improvements strain the human ability to compensate for system problems, future reverse engineers will surely question the wording of the ROC.

The requirements of the new ROC may exacerbate minor problems on the old BLACK HAWK.

THE NEW ROC: HUMAN ENGINEERING

Problem:
In cold weather, the crew and cargo compartment is not adequately heated. (First noted in OT II, 1976.)

-- Force Modernization Report No. 1, June 1983

New Requirement:
"The aircraft shall have a self-deployment capability with a minimum range of 1,150 nautical miles."

-- ROC for the BLACK HAWK Improvement Program, May 1982

Result:
This new requirement makes it much more critical that the aircraft be adequately heated.

New Requirement:
"Protective measures that shall restrict biological and chemical agents from entering into the cockpit from the cargo/passenger area (i.e., a transparent curtain) are required."

-- ROC for the BLACK HAWK Improvement Program, May 1982

Result:
The heating/ventilation problem is further compounded by this new requirement.

The ROC places new demands on the human and the hardware that designers of the old BLACK HAWK could not have anticipated.

THE NEW ROC: NEW DEMANDS ON HUMAN PERFORMANCE

"Space, weight, and power provisions for aircrew microclimate cooling are required. . . .

The aircraft shall have an integral single and multihook suspension system with a 12,000-pound load capability. . . .

Provisions for an air-to-air weapon system on the ESSS."

Source: *ROC for Improved BLACK HAWK*, May 1982.

The new ROC anticipates no changes in manpower/force structure requirements, even though tasks and skills for the operation, maintenance, and support of the system have yet to be assessed.

ROC for the BLACK HAWK improvement program states:

"Manpower force/structure assessment. The combat developer, in coordination with the materiel developer, has done a manpower force/structure assessment of the developing system and concurs that there will be no changes in the current manpower/force structure requirements."

How can this be so when just above this paragraph, the ROC states:

"Logistics assessment. The aircraft will be structured for standard Army logistical support and supported by standard TMDE and Army three-level maintenance. LSA/LSAR process will be used to determine and define logistics support and personnel tasks and skills for the operation, maintenance, and support of the system. The systems support package will be tested and evaluated during operational testing (OT)."

The new ROC persists in treating BLACK HAWK hardware and support systems as items to be developed separately. This is the same dichotomy that in the past has encouraged PMs and contractors to give more weight to hardware requirements at the expense of HMPT and logistics.

- BLACK HAWK cannot perform its missions without logistics support.
- The new Required Operational Capability treats the BLACK HAWK and its operation and maintenance support system as separate entities.
- Such a dichotomy encourages the program manager and the contractor to give more weight to hardware requirements than to human factors, manpower, personnel, and training and logistics requirements.

Training assessments have been made and specify that training devices will be modified to support training on the improved BLACK HAWK.

Training devices have yet to arrive for the "old" system.

THE NEW ROC: TRAINING

"Training Assessment. The combat developers and materiel developers have conducted the assessments required by paragraph 5d of the LOA. Based on the investigation, the following training products are required to support the improved BLACK HAWK when fully deployed:

A. Training devices are available to support training and will be modified to the block improvement configuration.

B. System technical manuals and materials will be in SPAS format.

C. New equipment training will be required to train instructor and key personnel prior to OT II and to support initial fielding of the system.

D. The requirement for extension training materials will be determined during the full scale development phase.

E. The training support package will be tested during OT II."

Source: *Required Operational Capability for Improved BLACK HAWK*, May 1982.

The BLACK HAWK helicopter's missions cannot succeed in its missions without operation, maintenance, and logistics support. The practice of treating the hardware and its support systems as separate entities in requirements documents, exemplified here, perpetuates the undue emphasis that materiel developers place on hardware requirements at the expense of HMPT and logistics requirements.

THE NEW ROC. . . .

- o May make old minor problems major problems,
- o Puts unanticipated demands on system,
- o Says "no additional manpower" though tasks and skills are not yet assessed,
- o Requires modification of training devices that still don't meet old required operational capability requirements.

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Conclusions

1. If human-caused failures are omitted from the evaluation, the BLACK HAWK met its hardware performance specifications in the areas of human factors, safety, and RAM.
2. Failure to define mission performance requirements fully makes it impossible to evaluate system (man/machine) performance.
3. Delays in the acquisition of mission flexibility kits, peculiar ground support equipment, test measurement and diagnostic equipment, and flight and maintenance simulators has cost time, money, and a lot of human ingenuity in compensating for the delays.
4. These findings all illustrate a concentration on hardware acquisition that makes it difficult to evaluate the performance of the man/machine system that is BLACK HAWK.

CONCLUSIONS

BLACK HAWK	Hardware performance specs met
Missions	Not defined fully
Associated equipment	Some still not available but the human tries to compensate
Result	A system that cannot be properly evaluated

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AFQT	Armed Forces Qualifications Test
AMIM	Army Modernization Information Memorandum
AMSAA	Army Materiel Systems Analysis Activity
ARI	Army Research Institute
ASARC	Army System Acquisition Review Council
AVUM	Aviation unit maintenance
BOIP	Basis of issue plan
COEA	Cost and operational electiveness analysis
CSAC	Combat Support Aviation Company
DPAMMH	Direct productive annual maintenance manhour
DA	Department of the Army
DCSPER	Deputy Chief of Staff for Pesonnel
DPQMR	Draft Proposed Qualitative Materiel Requirements
DSARC	Defense System Acquisition Review Council
DT/OT	Developmental & operational testing
FARRP	Forward area rearming and refueling point
FDIS	Fault Detection and Isolation Subsystem
FDTE	Force development test and experimentation
FORSCOM	U.S. Army Forces Command
FS	Flight simulation
FSED	Full-Scale Engineering Development
GCT	Government Competitive Tests
HFE	Human factors engineering
HMPT	Human factors, manpower, personnel, and training
IOC	Initial Operational Capability
LCSMM	Life Cycle System Management Model
LSAR	Logistics Support Analysis Record
MACRIT	Manpower authorization criteria
MAP	Manpower analysis paper
MFK	Mission flexibility kit
MIST	Man Integrated Systems Technology
MLRS	Multiple Launch Rocket System
MN	Materiel Need
MNED	Materiel Need Engineering Development
MTBF	Mean Time Between Failures
MOE	Measures of effectiveness
NOE	Nap-of-the-earth
PGSE	Peculiar ground support system
PM	Program Management
PM-TRADE	Program Manager--Training Devices & Equipment
POM	Program objective memorandum
QMDO	Qualitative Materiel Development Objective
RAM	Reliability, Availability, and Maintainability
RFP	Request for Proposal
ROC	Required Operational Capability

TDS	Training Development Study
TMDE	Test Measurement and Diagnostic Equipment
TOE	Table of Organization & Equipment
TRADOC	U.S.Army Training & Doctrine
TRASANA	TRADOC Systems Analysis Agency
USASC	U.S. Army Safety Center
USATSCH	U.S. Army Transportation School
UTTAS	Utility Tactical Transport Aircraft System
WSAP	Weapons system acquisition process